New Algorithm and Processor for Obtaining Maritime Information from Sentinel-1 Radar Imagery for Near Real Time Services

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- **Examples and concept**
- **Background**
- **Model Functions Tuning**
- **NRT implementation**
- **Outlook**

DLR

Short description

The **new empirical algorithm** allows estimation of **total integrated sea state parameters** and **also partial integrated parameters** including

- significant wave height H_s,
- first moment wave period T_{m1},
- second moment period T_{m2},
- mean period T_m
- like swell (dominant and secondary) and windsea wave heights S_{w1}, S_{w2}, S_{ww}
- windsea period T_w.

The algorithm allows processing of different S1 Synthetic Aperture Radar (SAR) modes with different resolution into **sea state fields**:

- For **Sentinel-1 S1 Wave Mode (WV)**, acquires multiple vignettes with an extent of ~20km×20km and each displaced by 100 km along satellite tracks in open ocean (global) with relatively high spatial resolution of ~4 m wave height can be estimated with **accuracy of ~35cm**. This is comparable with the accuracy of satellite altimetry and a new achievement for SAR based techniques.

- For **Sentinel-1 Interferometric Wide Swath Mode (IW)** covers area-strips of thousand kilometres of earth and ocean surface in coastal areas with a resolution of ~20m by sequences of multiple images with an approximate size of 200km×250km the accuracy of ~ 70cm
-

The **algorithm has been integrated into** a prototype processor for Sentinel-1 SAR imagery. The DLR **Ground Station Neustrelitz** applies this prototype **as part of a near real-time demonstrator MSA service**.

1. Concept and Examples

2. Background

3. Model Functions, Tuning

4. NRT implementation

5. Outlook

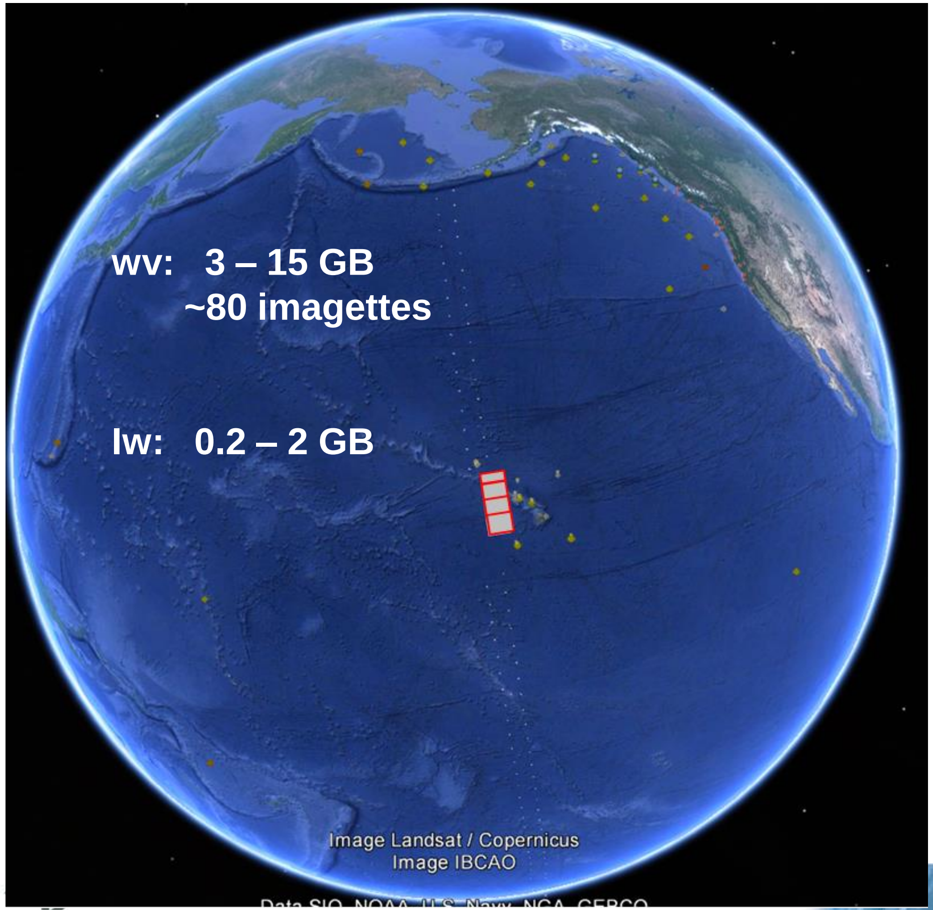
1.1. Sentinel 1A, 1B IW und WV Modi

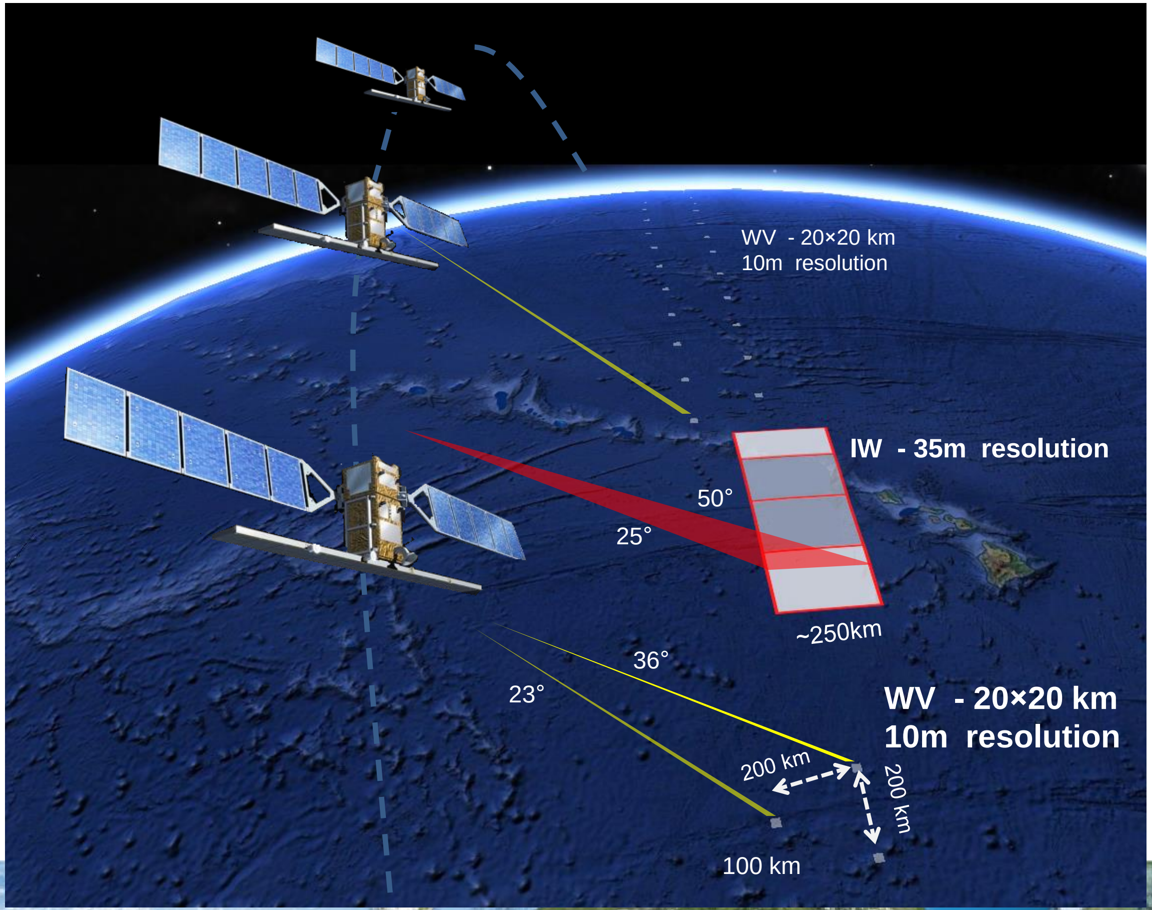
Sentinel-1A - 2014
Sentinel-1B - 2016

► flight 704 km
► ground speed 6.8 km/s
► C-Band Radar with wavelength of 5.6 cm

►**IW -** Interferometric Wide Swath Mode - **Coastal areas**
~ 200 km × 250 km, ~ 35m resolution, 10m pixel
GRDH: level-1 Ground Range Detected High-resolution products

► **WV -** Wave Mode - **Ocean**
~ 20 km × 20 km vignette each 100 km, ~ 5m pixel
SLC: Single Look Complex products

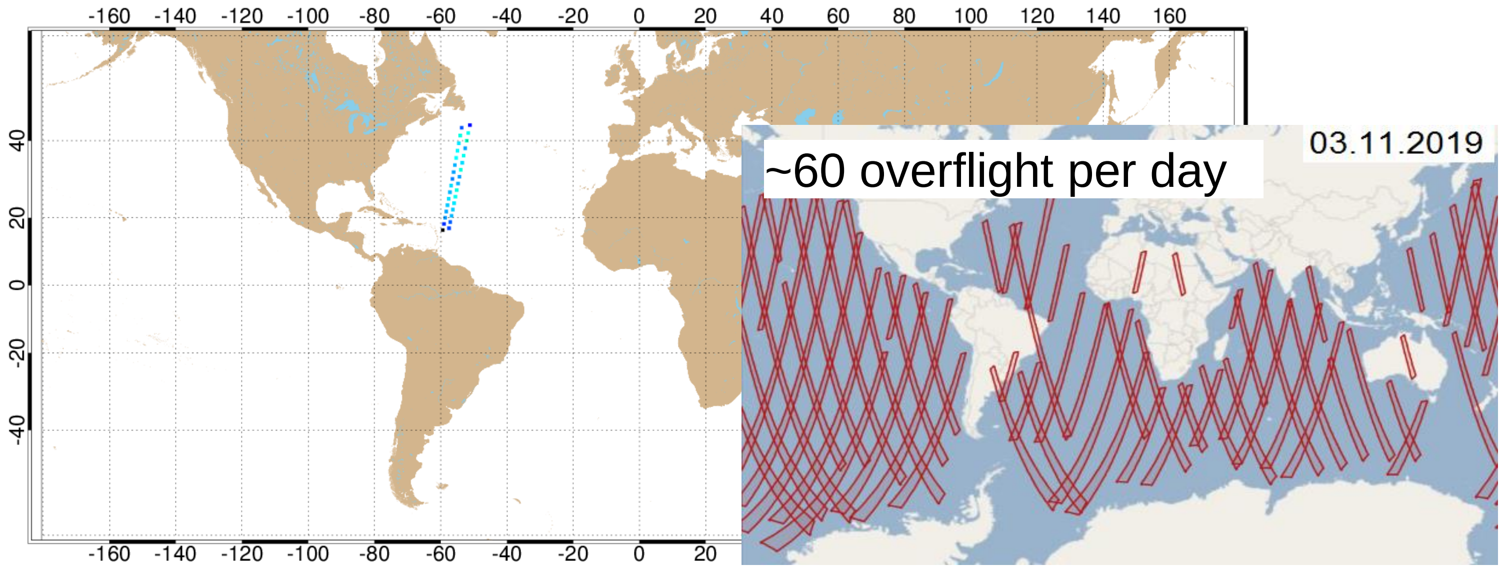




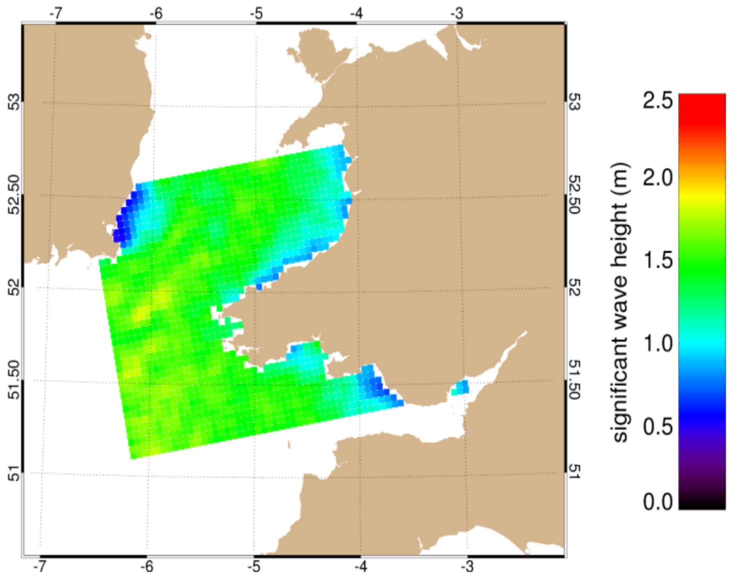
1.2. New sea state processor S1 IW and WV

New method allows estimating series of integrated sea state parameters for both S1 WV (tracks) and IW (fields)

S1 WV



S1 WV



RMSE

	SWH	Tm0	Tm1	Tm2	Sw1	Sw2	Sww	Tw
S1 IW	63cm	1.15 sec	0.95 sec	0.79 sec	0.52 m	0.38 m	0.73 m	0.92 sec
S1 WV	35cm	0.64sec	0.52 sec	0.53 sec	0.42 m	0.35 m	0.41 m	0.65 sec

Total integrated partial integrated

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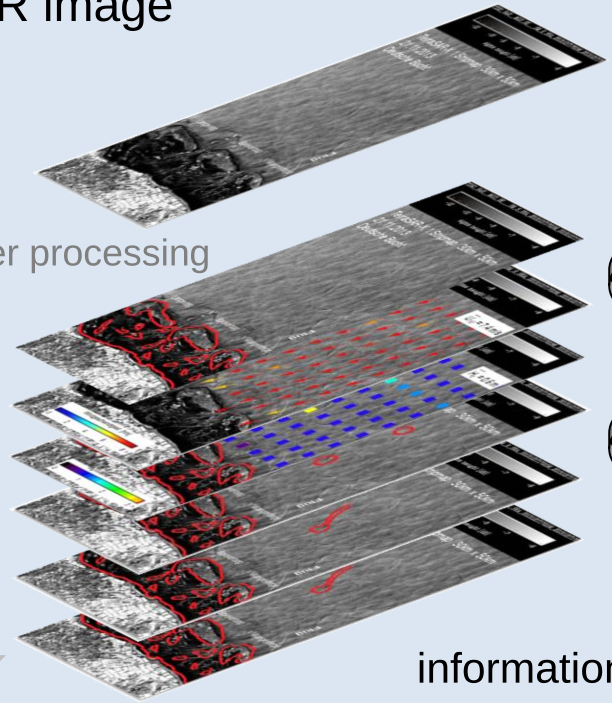
1.3. Concept: maritime situation awareness (MSA) for safe navigation

Integrated Processor for MSA: Near Real Time services(NRT)

DLR Maritime safety and security Lab Bremen
algorithms and **processor** development

coupled processor

SAR image



layer processing

coastline

surface wind

sea state

ship detection

oil detection

ice classification

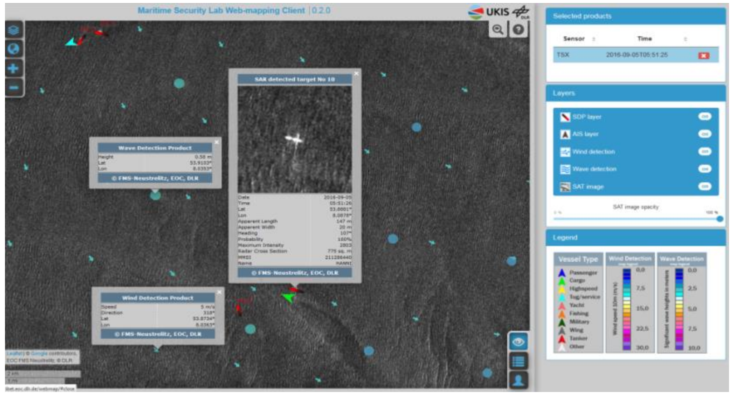
fast, full automatic raster processing

information from different layers helps each over and improve accuracy

DLR Ground Station Neustrelitz (NZ)
NRT chain

operationally:
-sea state
-wind
-ships
-icebergs

NRT products



Map client, ftp, E-mail

FUSION
WITH DATA FROM OTHER SOURCES

+ measurements
+ forecast
+ ship AIS

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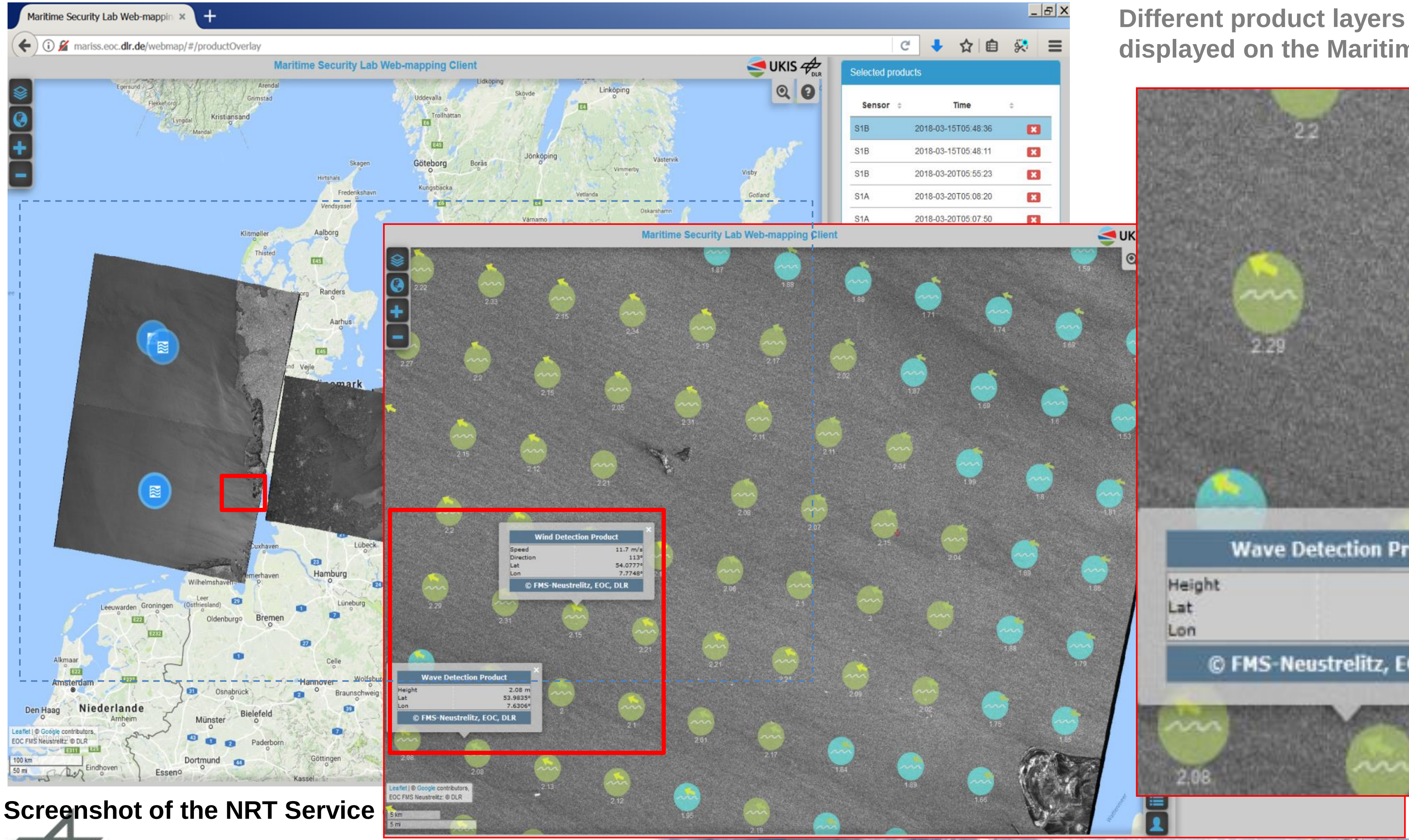
1.4. Sea State Processor for Maritime Situation Awareness

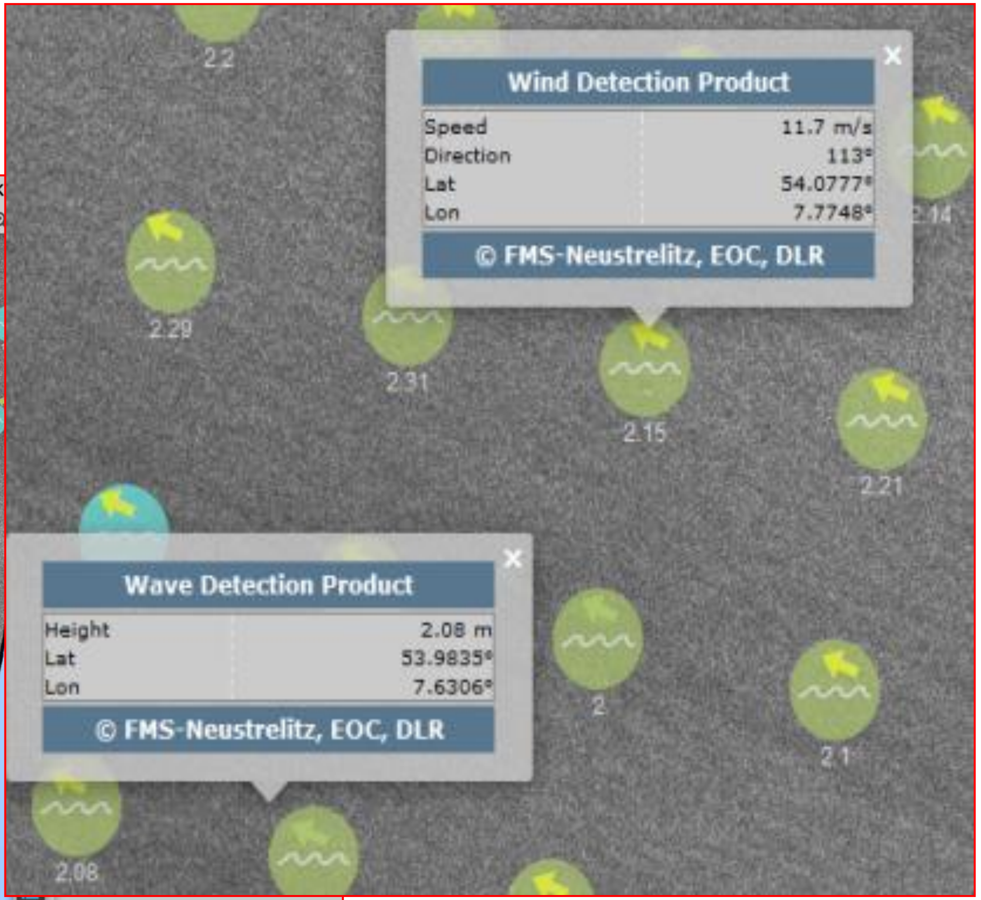
NRT services: SENTINEL-1 waves, wind, ships

Raster: 6 km, **Subscenes**: 2.5kmx2.5km



Screenshot of the NRT Service

Different product layers available on the GeoServer in NRT and displayed on the Maritime Security Web-mapping Client.



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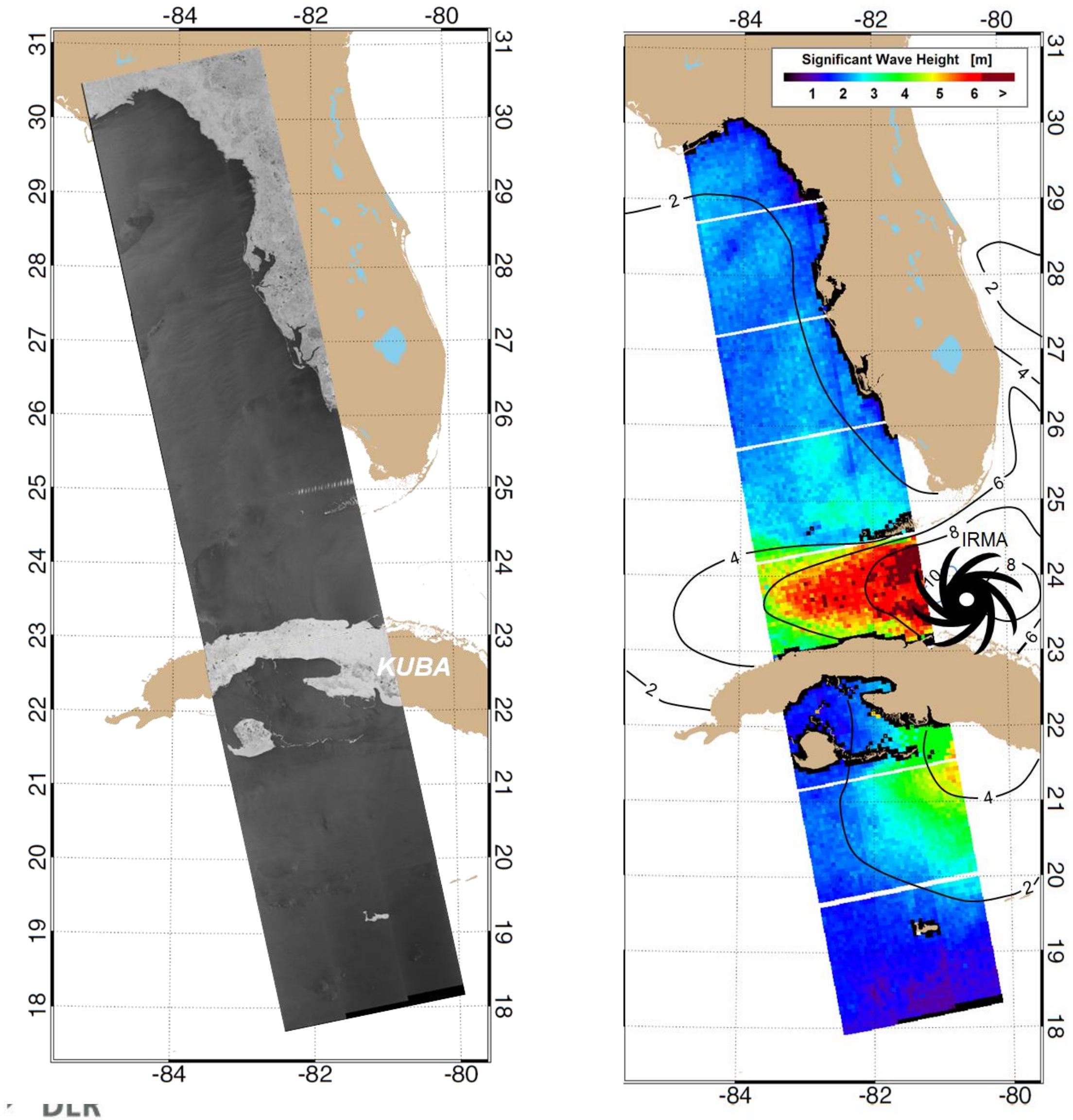
1.5. Sea State Processor Example Hurricane Irma – ESA news

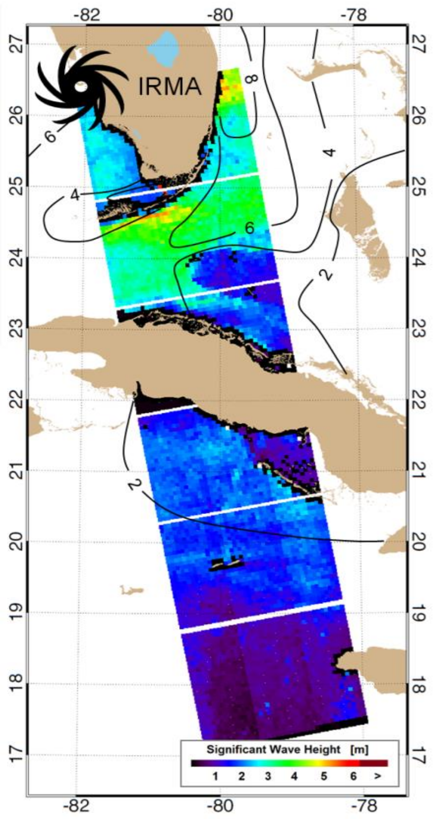
Hurricane „Irma“ 2017 (S-1)

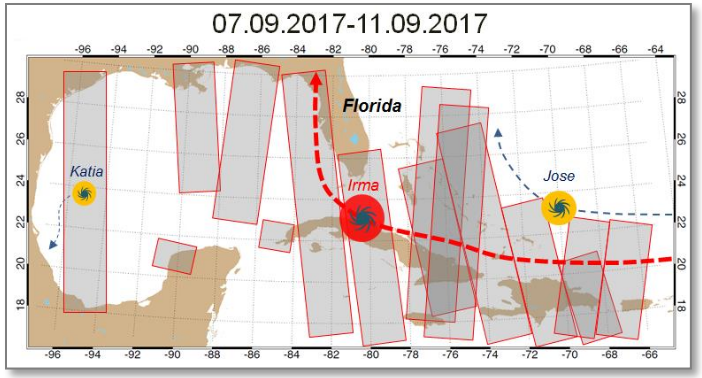
SENTINEL S-1 IW VV 2017-09-09 23:33 UTC TOTAL SIGNIFICANT WAVE HEIGHT

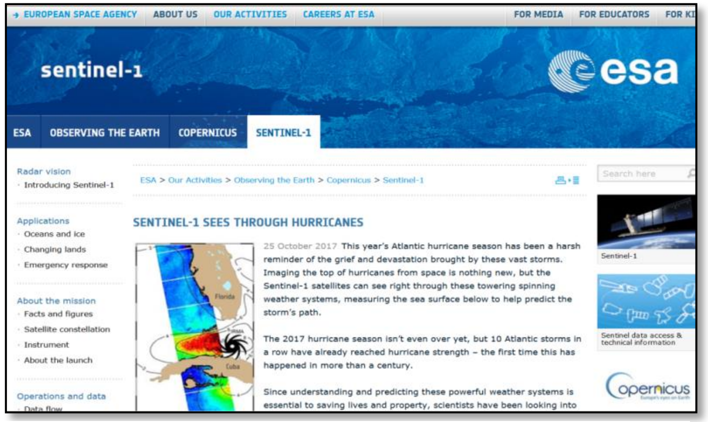


new techniques and algorithms allow observation and validation of forecast models worldwide

2017-09-10 23:25 UTC



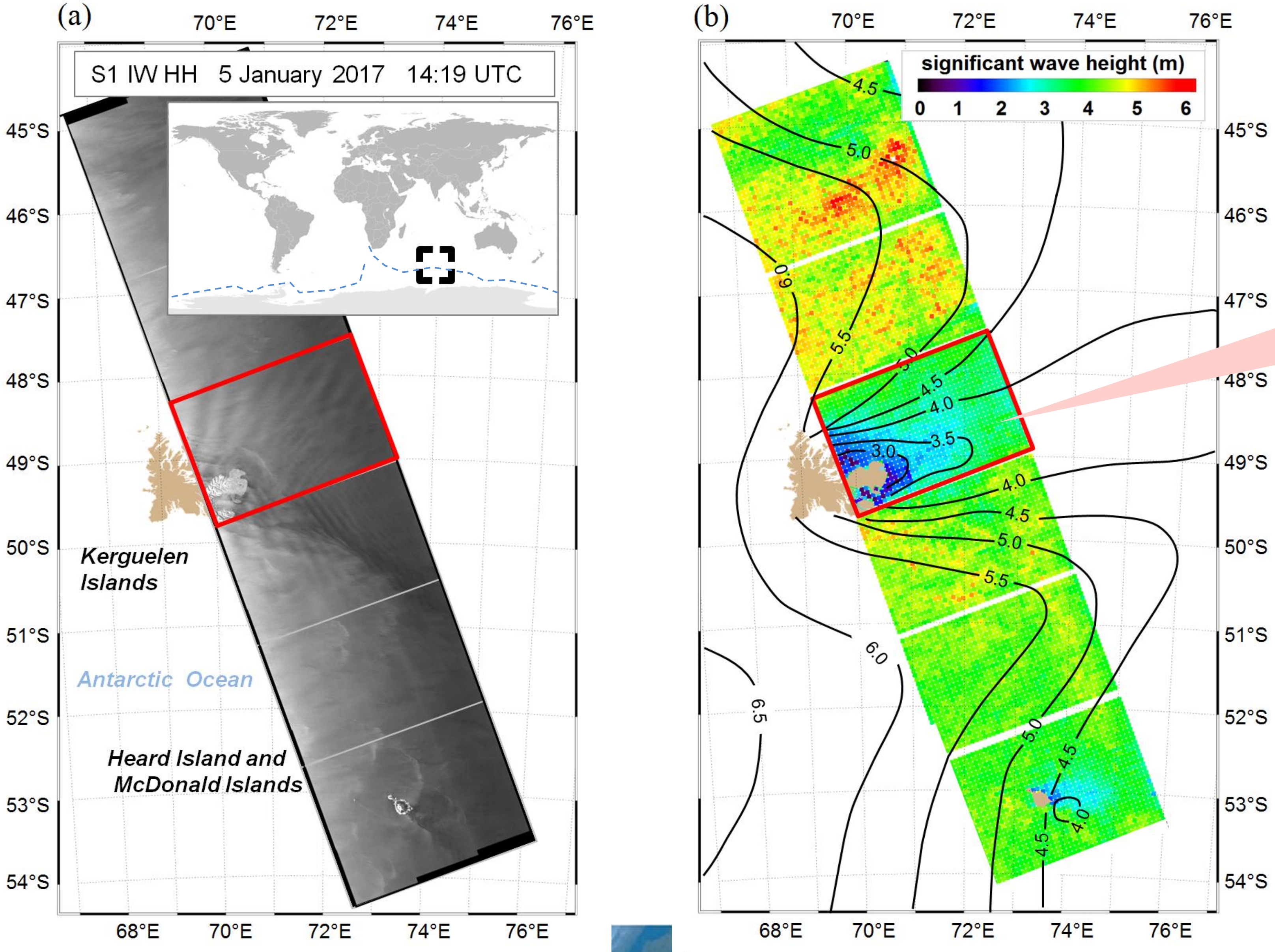




ESA news:
Sentinel-1 sees through hurricanes

“… information about the sea state can help to assess how destructive a hurricane is and can predict its path respectively time and location on which it will make landfall ….”

1.6. Support of a research cruise in Arctic Seas – navigation and routing



Arctic Sea, 05.01.2017

Processed in NRT
And send to research vessel “Akademik Treshnikov” on Antarctic Circumnavigation

1.7. Following a storm in the Black Sea: 3 days (S-1)

Total Significant Wave Height | Black Sea storm 20-23.04.2017 | SENTINEL -1 SAR C-band IW mode | processing mesh 6km×6km

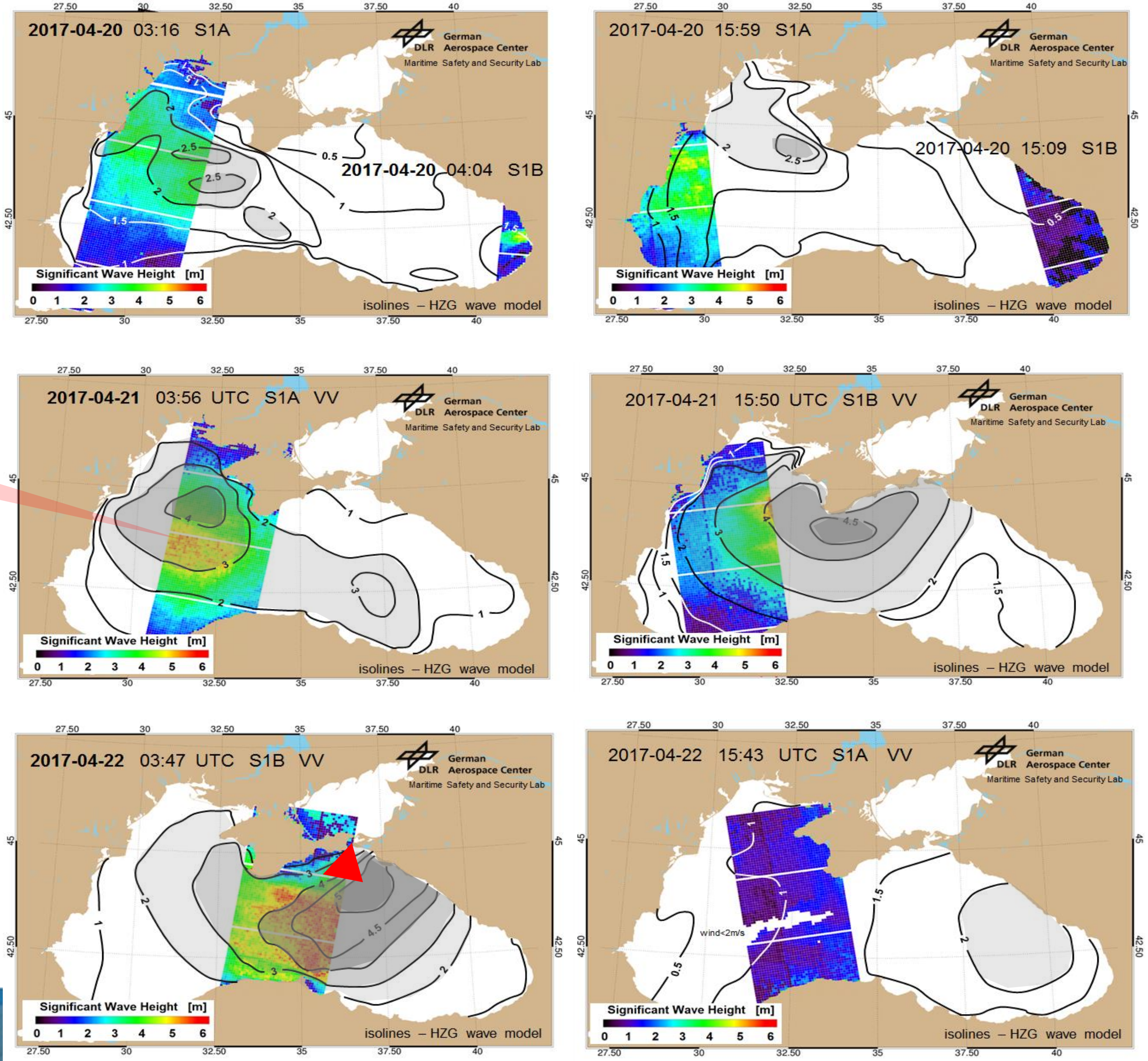
descending path ~03:00 UTC

ascending path ~16:00 UTC

2017-04-20

2017-04-21

2017-04-22



Modelled storm peak
~90 km northerly

114-m long cargo vessel with 12 crew sinks

Raging Black Sea storm
splits cargo ship in half

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2.1. Background: Objective

1. Basic Research - Functions & Algorithms

SAR Imaging Mechanism: Geophysical Model Function (GMF): development and adoption

- mathematic investigations
- for practical applications

2. Software Development - Prototype & NRT Processors

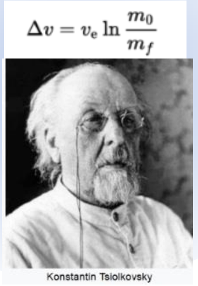
– implementation of GMF into Processors (SSP) prototype
– implementation of SSP into processing chain for NRT cervices,

3. Processing and Results Analysis - What do we learn?

Forecasts improvement and geophysics

– statistics, local distributions
– extreme events
– assessments, danger localization, follow up and validation of forecast models (e.g. DWD)

Tsiolkovsky rocket equation 1903

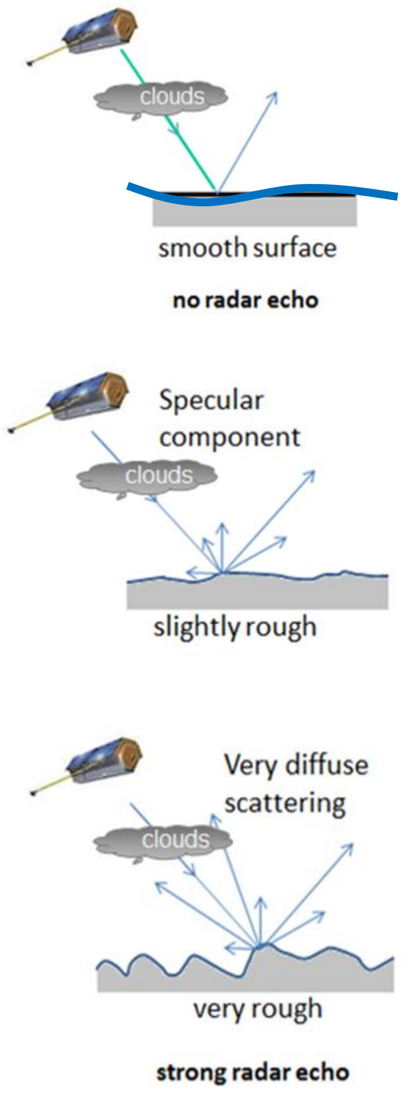


first human in space

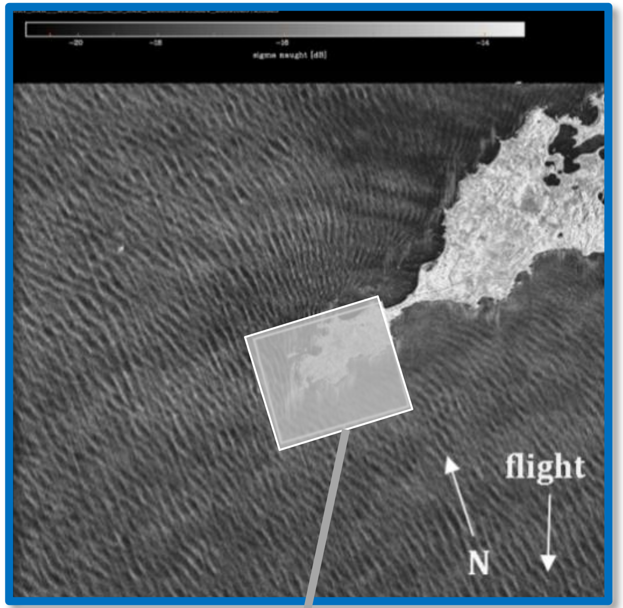
International Space Station 1998

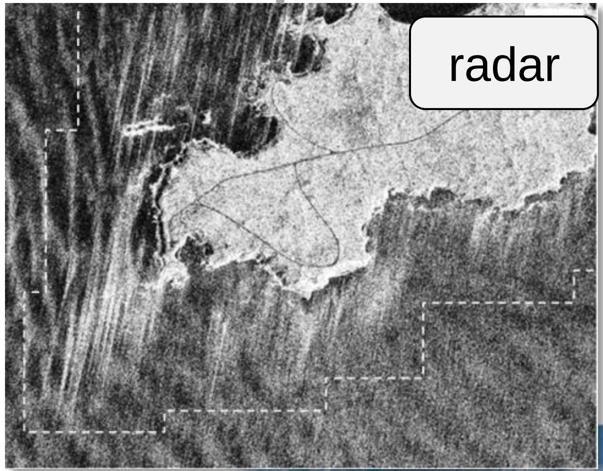
2.2. Satellite Radar Imagery

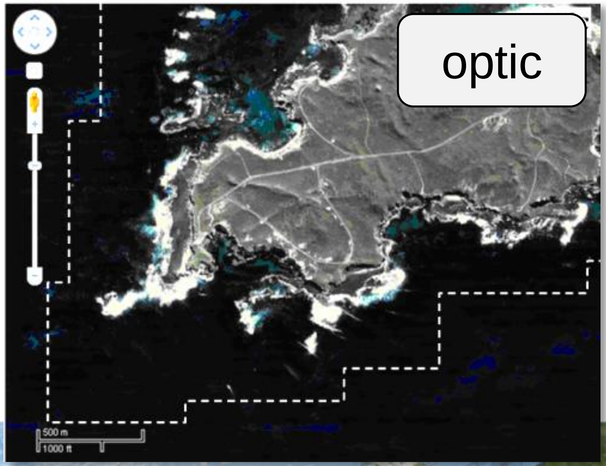
Imaging of sea surface by radar



active sensor







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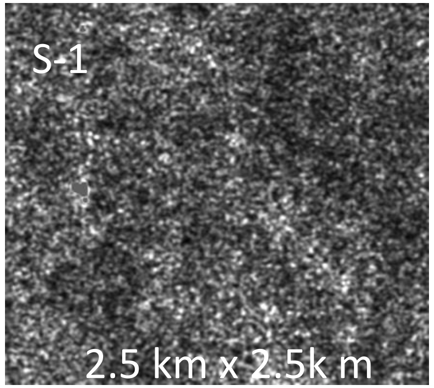
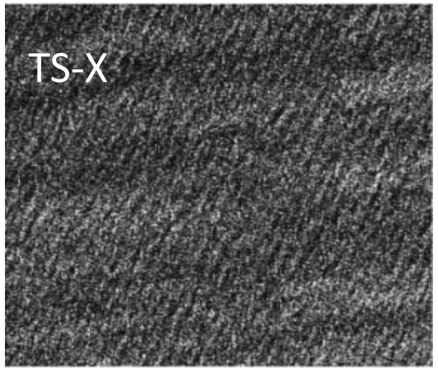
2.3. Sea surface by different sensors

SENTINEL S-1 IW VV 10m Pixel, C-band
TerraSAR-X StripMap VV 1.25m Pixel, X-band

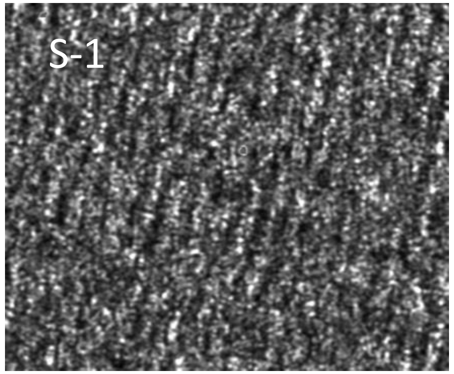
Hs ~ 0.5m

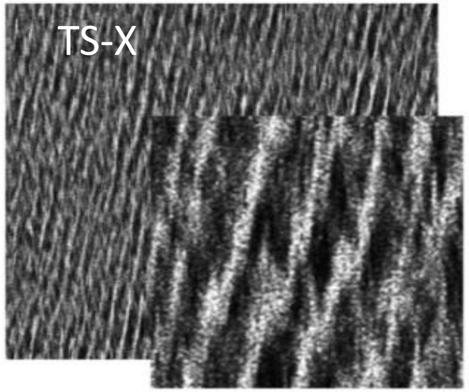




calm (swell)

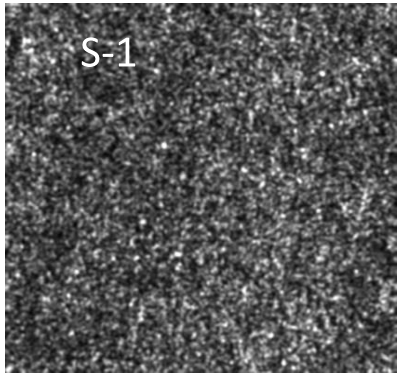
Hs ~ 4m

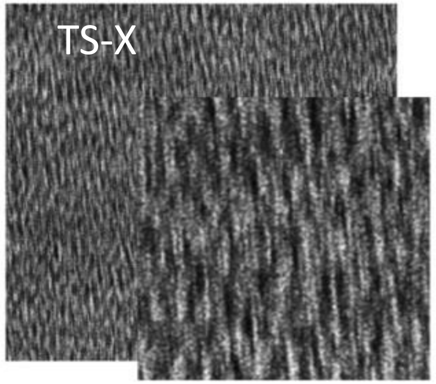




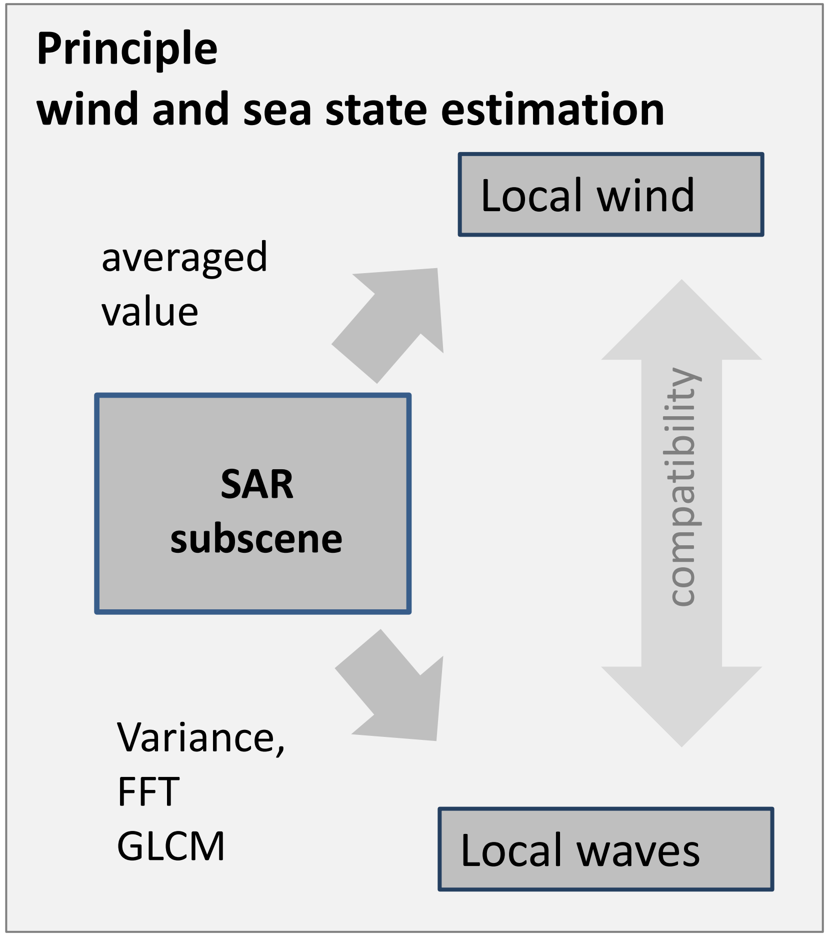
moderate

Hs ~ 7m





strong



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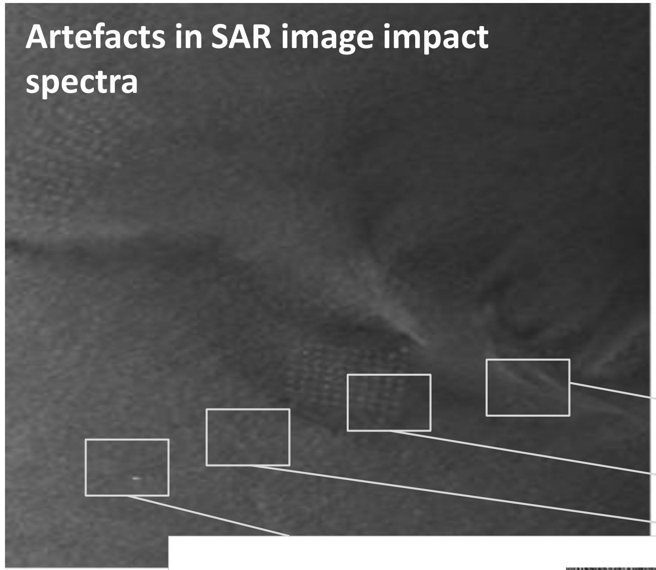
2.4. Artefacts pre-filtering



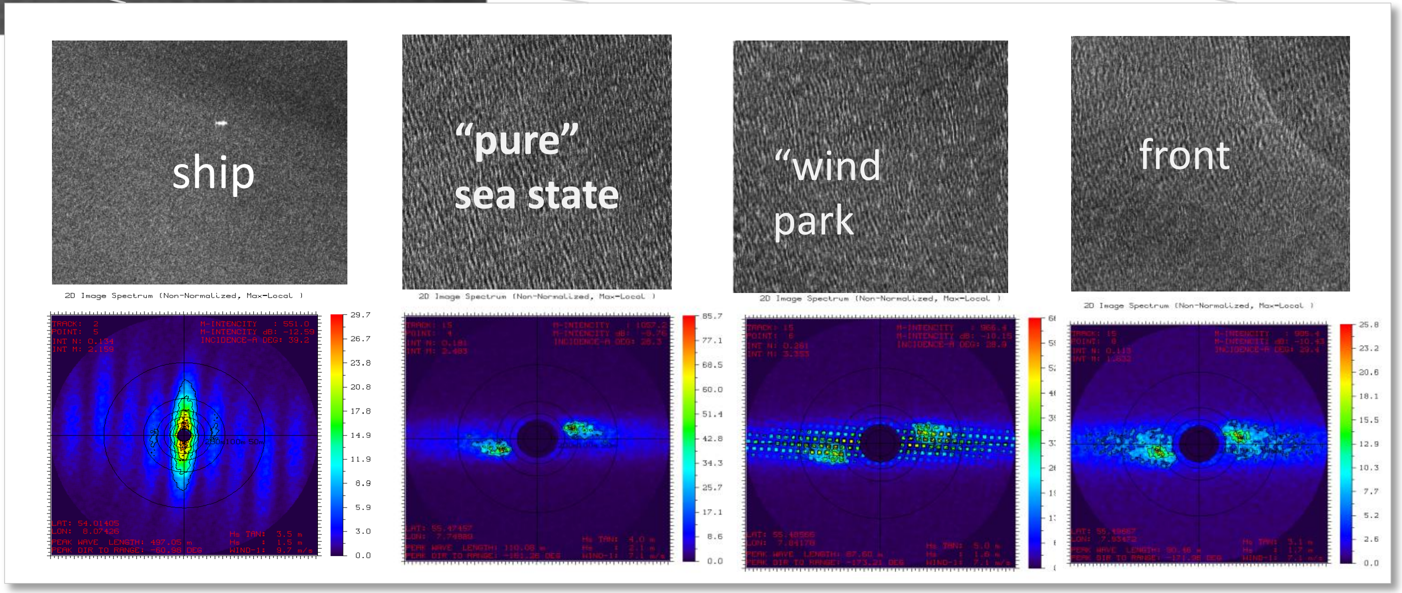
Task №1 - removing artefacts before analysis

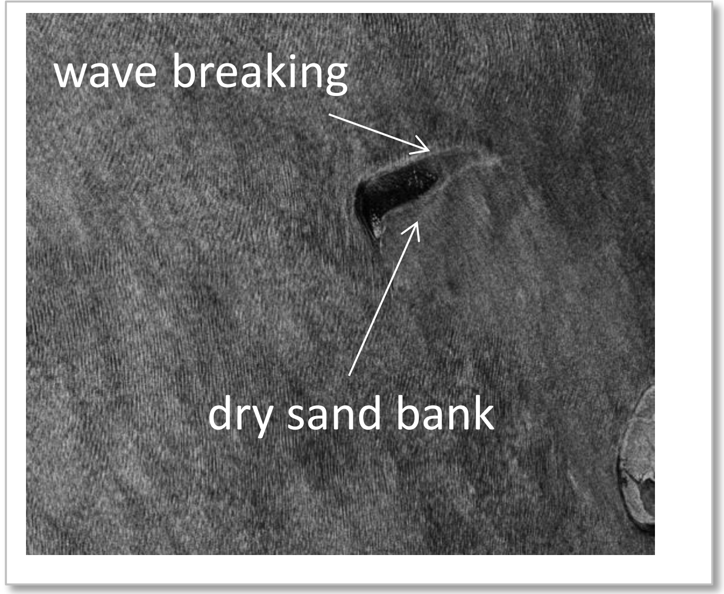
- Sand banks
- Wave breaking
- Ships, Buoys, Wind farms
- Current fronts, ship wakes

Without pre-filtering estimated *Hs* can > 10 times overestimate real value

3 STEPS

▶ Removing before analysis
▶ Function correction terms
▶ Control results





3.1. Empirical Function and Parameter (SAR features)

Function: linear regression

$$P_i = \sum_{n=0}^{N} A_n S_n$$

Solution: quadratic minimization using SVD (singular value decomposition) – optimal solution for a linear system

SAR features type	Parameters first order
1. Subscene properties and statistics	NRCS, Norm.-variance, skewness, kurtosis, *+ 5 additional parameters (will be published later)*
2. Geophysical	Wind
3. GLCM (grey level co-occurrence matrix)	GLCM-mean, variance, entropy, correlation, homogeneity, contrast, dissimilarity, energy
4. Spectral-A	using spectral bins for different wavelengths Goda-parameter, Longuet-Higgins-parameter, *+ 5 additional parameters (will be published later)*
5. Spectral-B	20 parameter by using orthonormal functions, cutoff by ACF (autocorrelation function)

3.2. Model Function

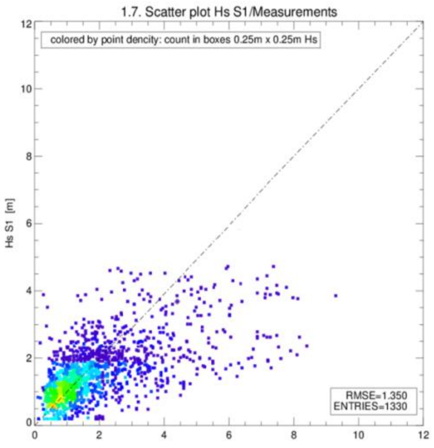
Linear regression Empirical Model Function (EMF) bases on parameters

- Image spectral parameters (20 par.)
- Local wind information, variance
- GLCM (Grey Level Co-Ccurrance Matrix) parameters (Entropy, Homogeneity, Contrast, Dissimilarity, etc.)

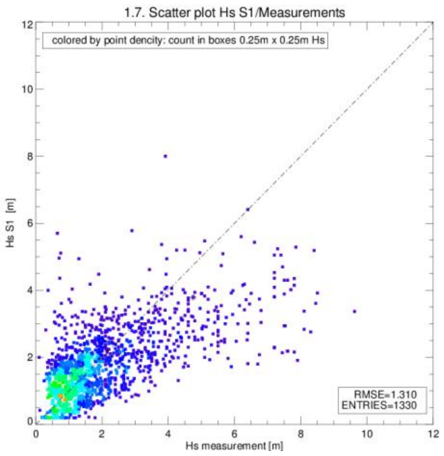
$$W = a_0 + \sum_{i=1}^{n_s} a_i s_i$$

Model Function tuning – combination of spectral and Image feature analysis + filters

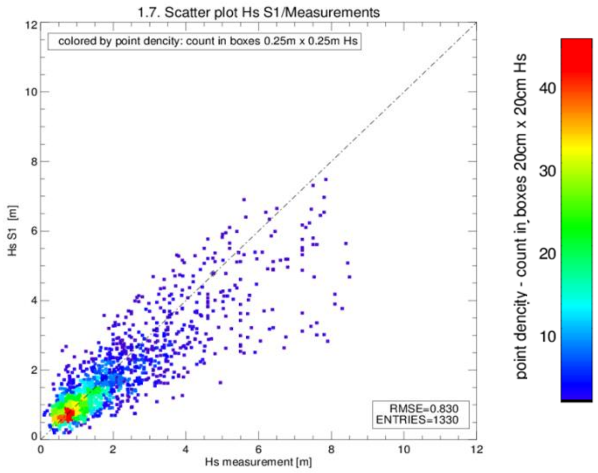
- tuning by minimizing root mean squared error RMSE
- number of used features improve results



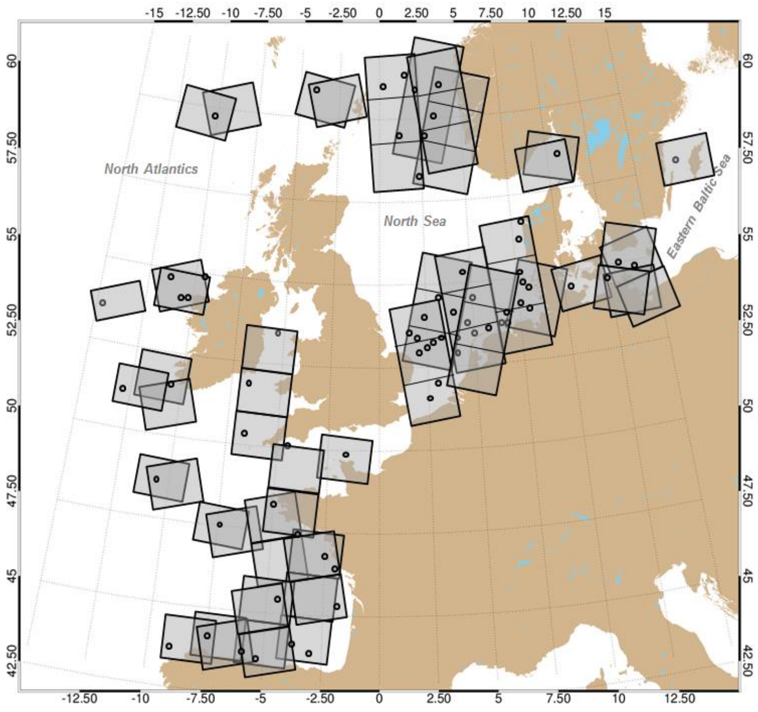
Tuning using
local **wind U_{10} only**
(optimal RMSE =1.35m)



Tuning using
integrated spectrum energy only
(optimal RMSE =1.31m)



Tuning using:
- **integrated image spectrum energy**
- **local wind U_{10}**
- **spectral parameters**
- **GLCM parameters** (optimal RMSE =0.83m)



Example for collocations of individual S1 IW images with measurement stations in the **North Sea, Eastern Baltics and North Atlantics** used for algorithm tuning and validation.

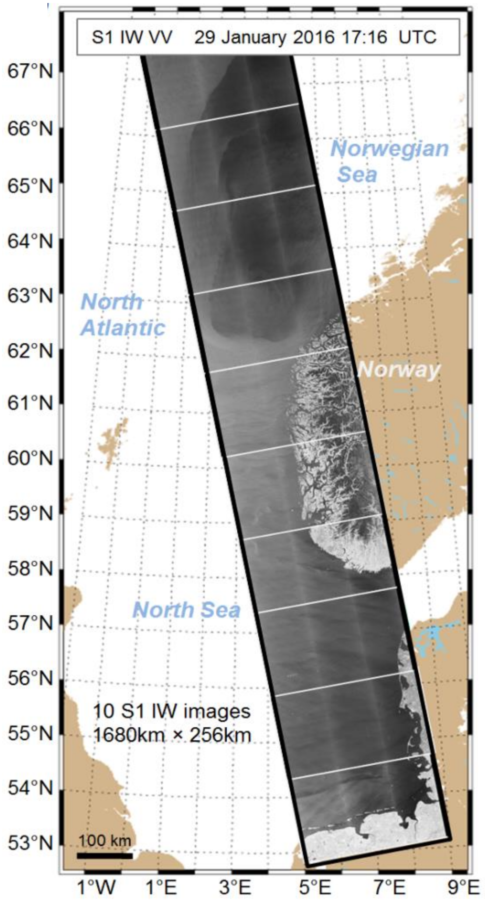
3.3. Model Function – example features estimation

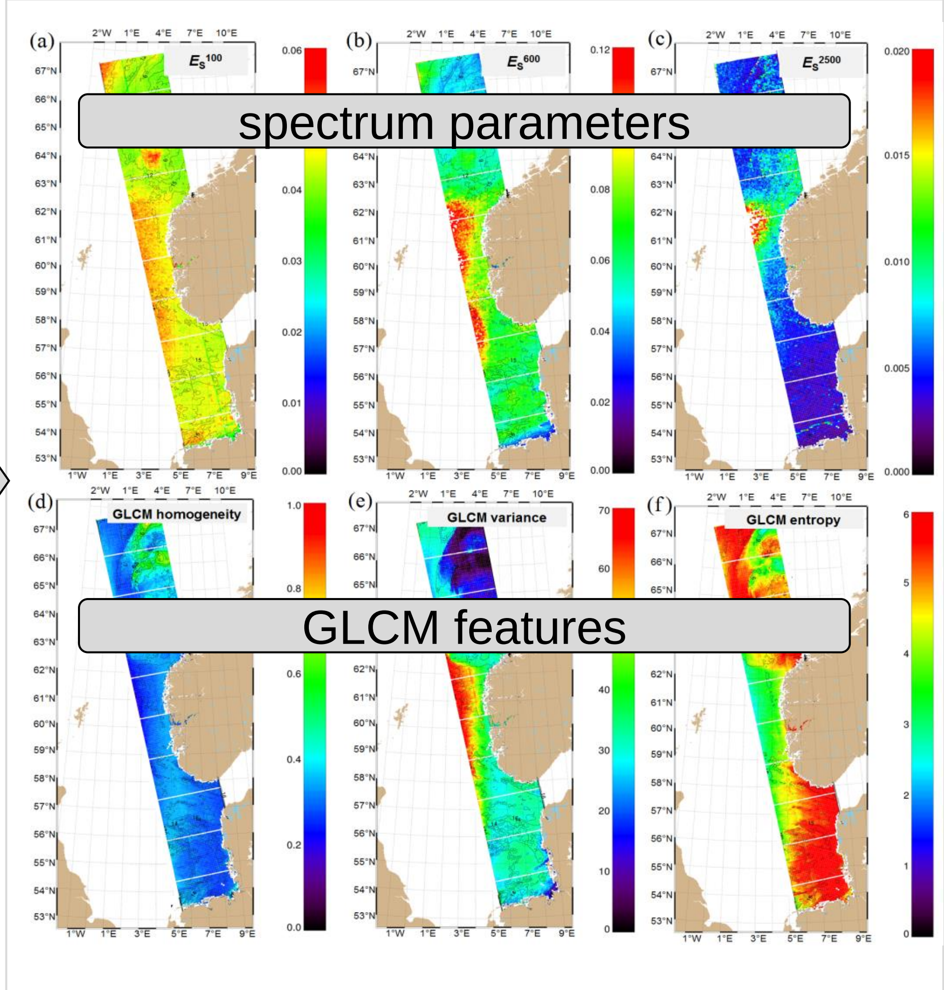
Linear regression Empirical Model Function (EMF) bases on parameters

- Image spectral parameters (20 par.)
- Local wind information, variance
- GLCM (Grey Level Co-Ccurrance Matrix) parameters (Entropy, Homogeneity, Contrast, Dissimilarity, etc.)

$$W = a_0 + \sum_{i=1}^{n_s} a_i s_i$$

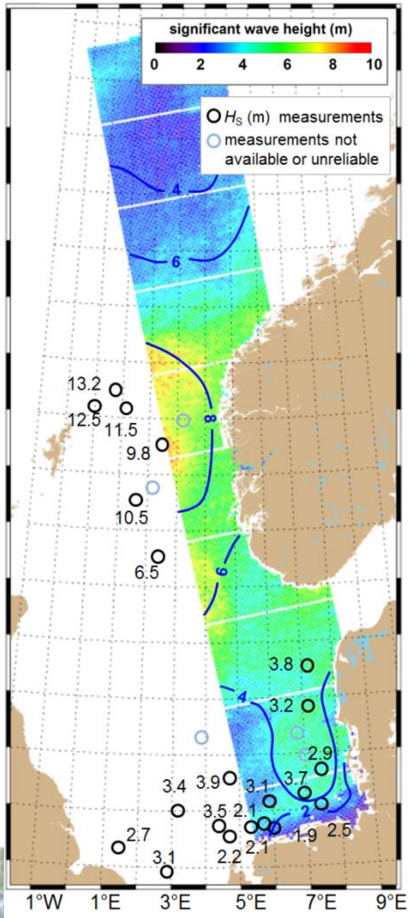
S1 IW scene

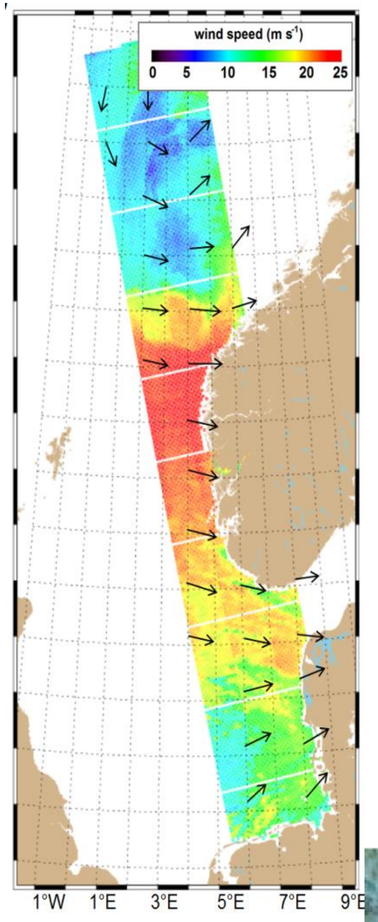




Wind

Waves



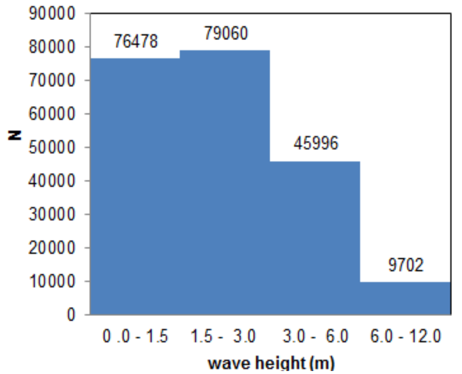


3.4. New sea state processor 2020: SWH improvement IW

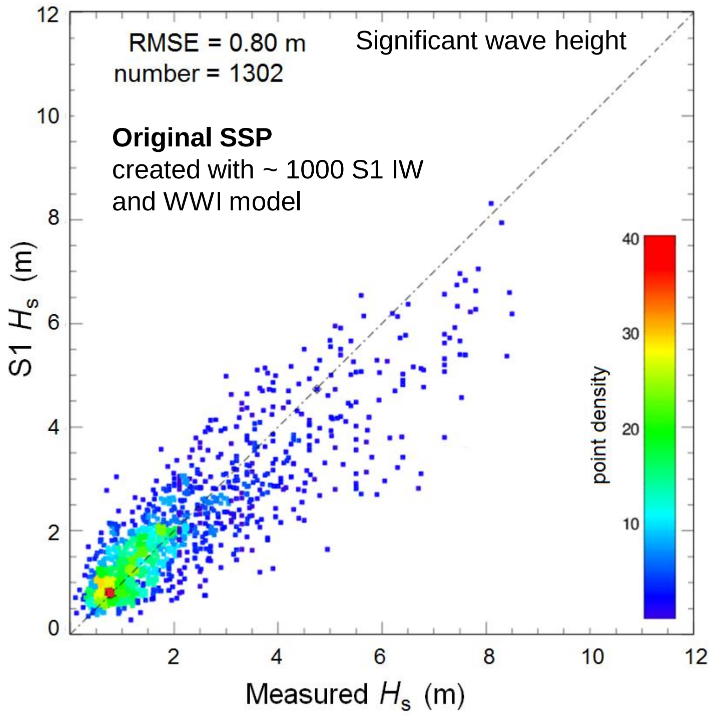
New processor 2020 **SAINT Sea State Processor SSP for sea state fields estimation**

- **New function with new parameters**
- **New S1 IW acquisition (~ 2000) + new validation data -**
  CMEMS model results with ~5km resolution worldwide (/WW3 ~30km resolution)
- **New software**

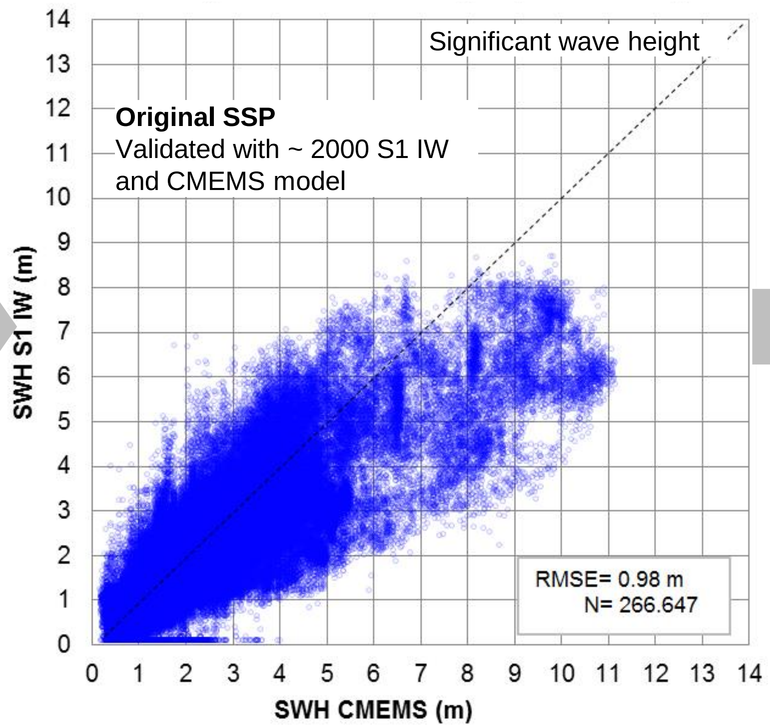
- **Higher accuracy for SWH + additional parameters**



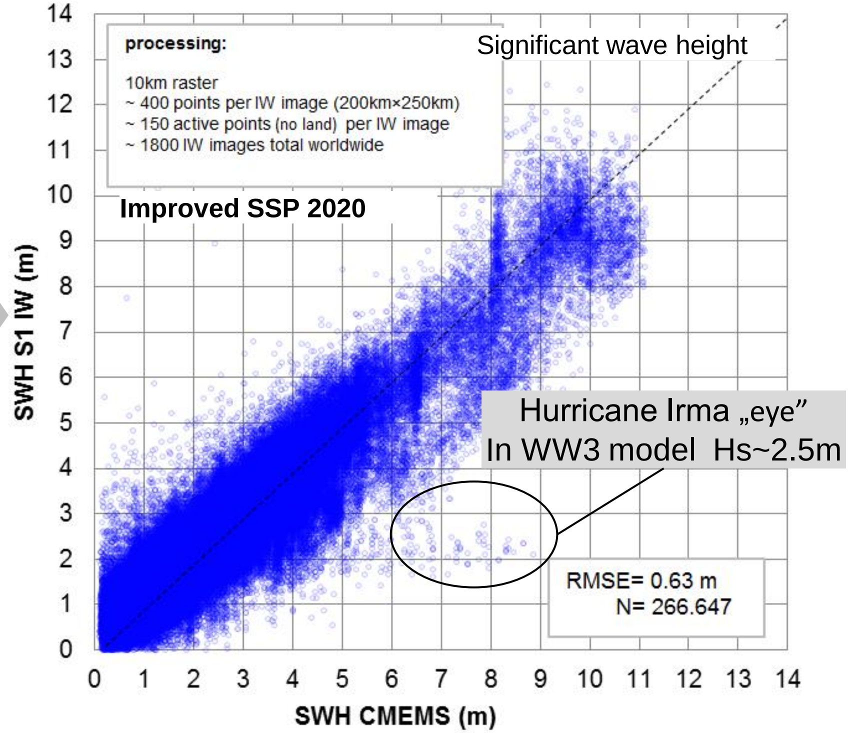
SSP V1-2017 ~ 1000 S1-IW



SSP V1-2017 ~ 1000 S1-IW

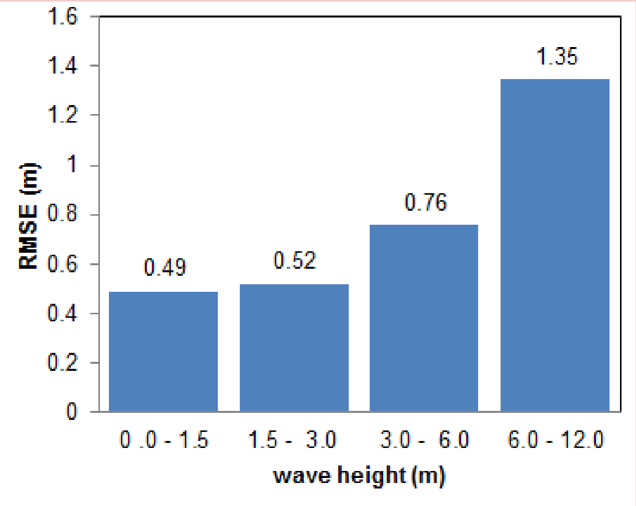


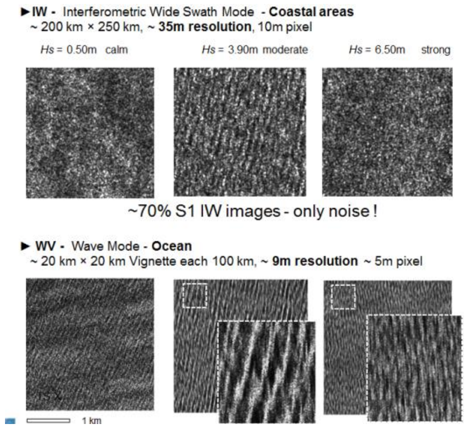
SSP improved 2020



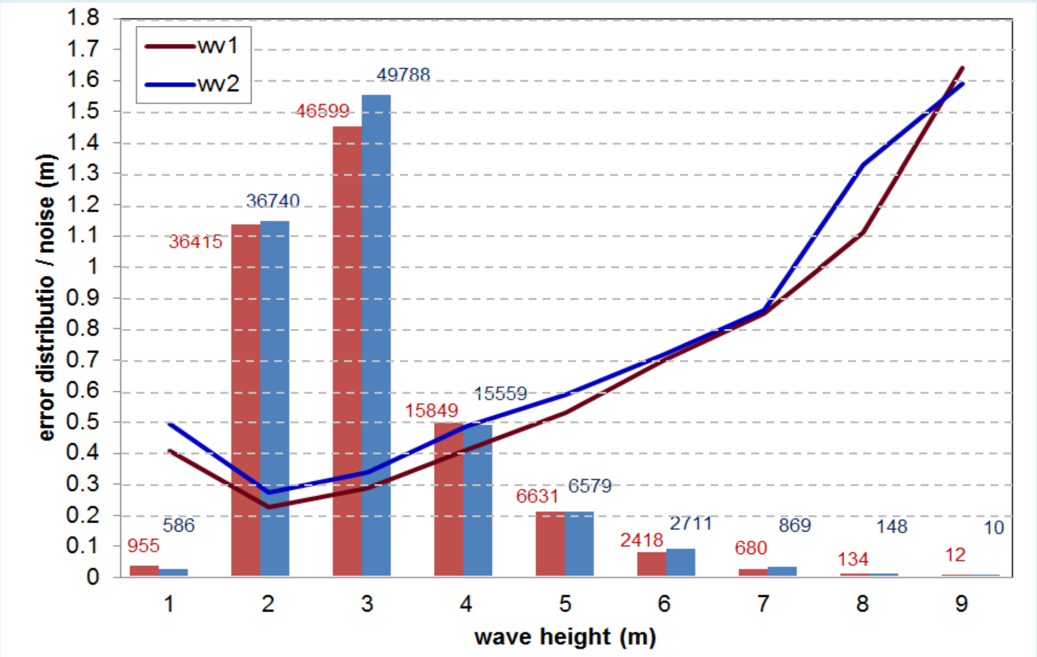
3.5. Accuracy: new sea state processor S1 IW and WV

Error distribution SWH S1 IW





Error distribution SWH S1 WV

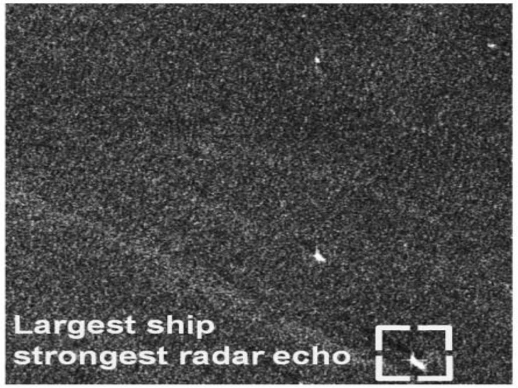


RMSE

	SWH	Tm0	Tm1	Tm2	Sw1	Sw2	Sww	Tw
S1 IW	63cm	1.15 sec	0.95 sec	0.79 sec	0.52 m	0.38 m	0.73 m	0.92 sec
S1 WV	35cm	0.64sec	0.52 sec	0.53 sec	0.42 m	0.35 m	0.41 m	0.65 sec

4.1. Sea State Processor for SENTINEL-1 and TerraSAR-X at Ground Station NZ

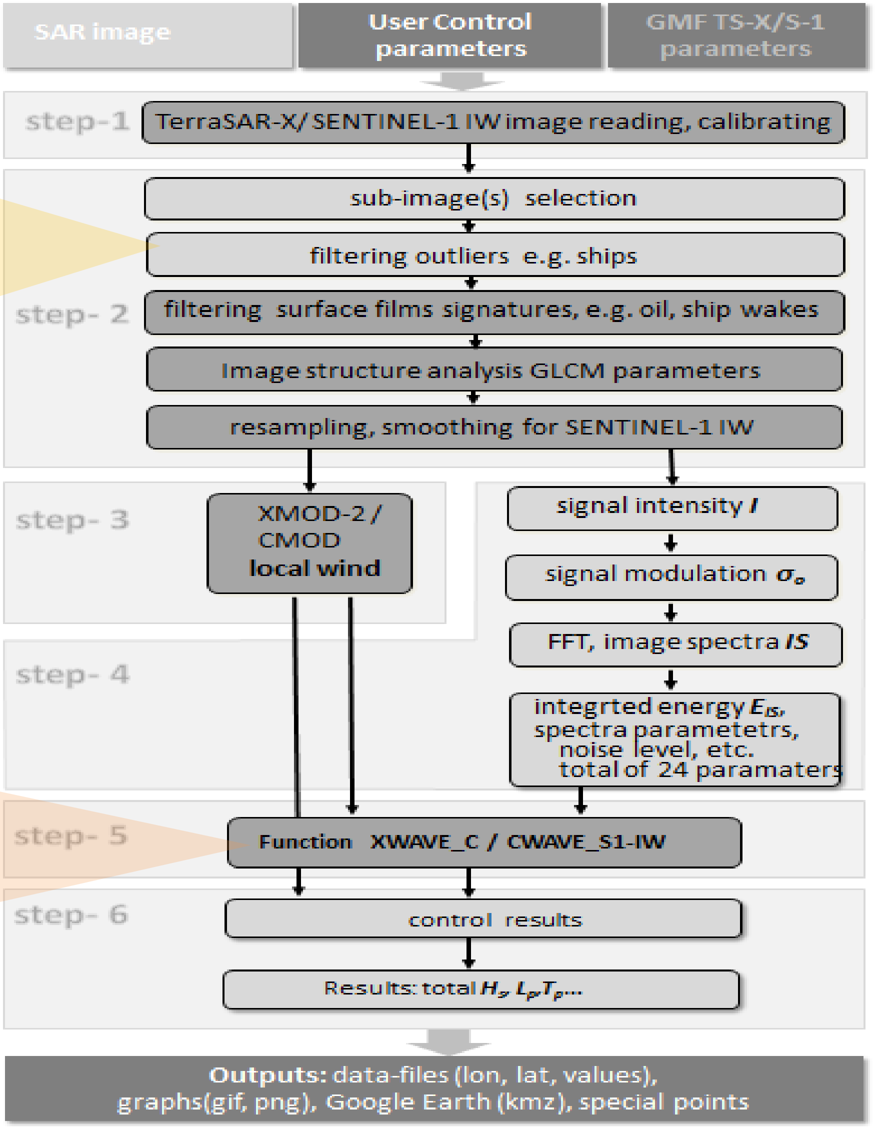
artefact pre-filtering

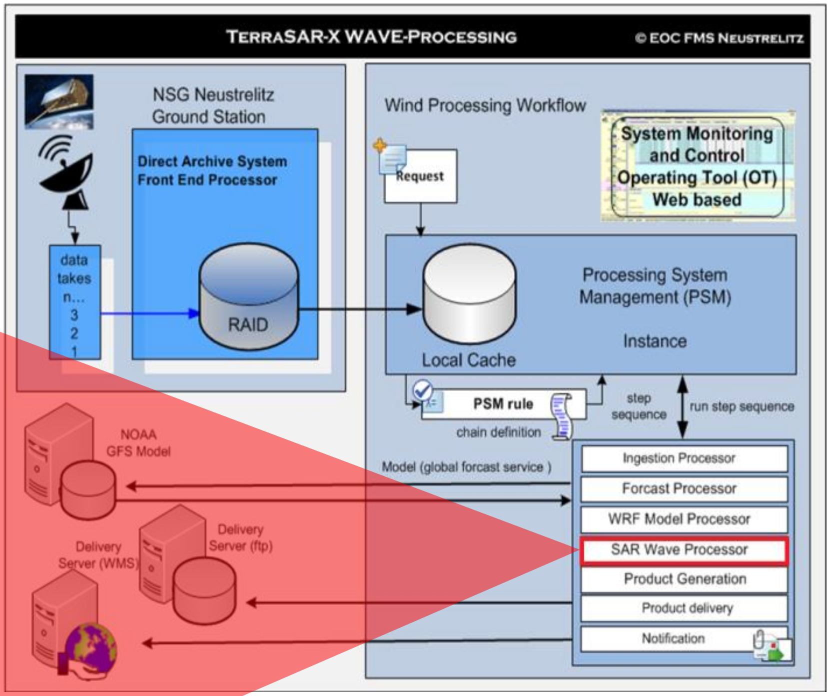


Sea State Functions
TerraSAR-X
Sentinel-1

- **Spectral parameters**
- **Local wind**
- **GLCM parameters**

Sea State Processor





NRT chain in Neustrelitz NZ

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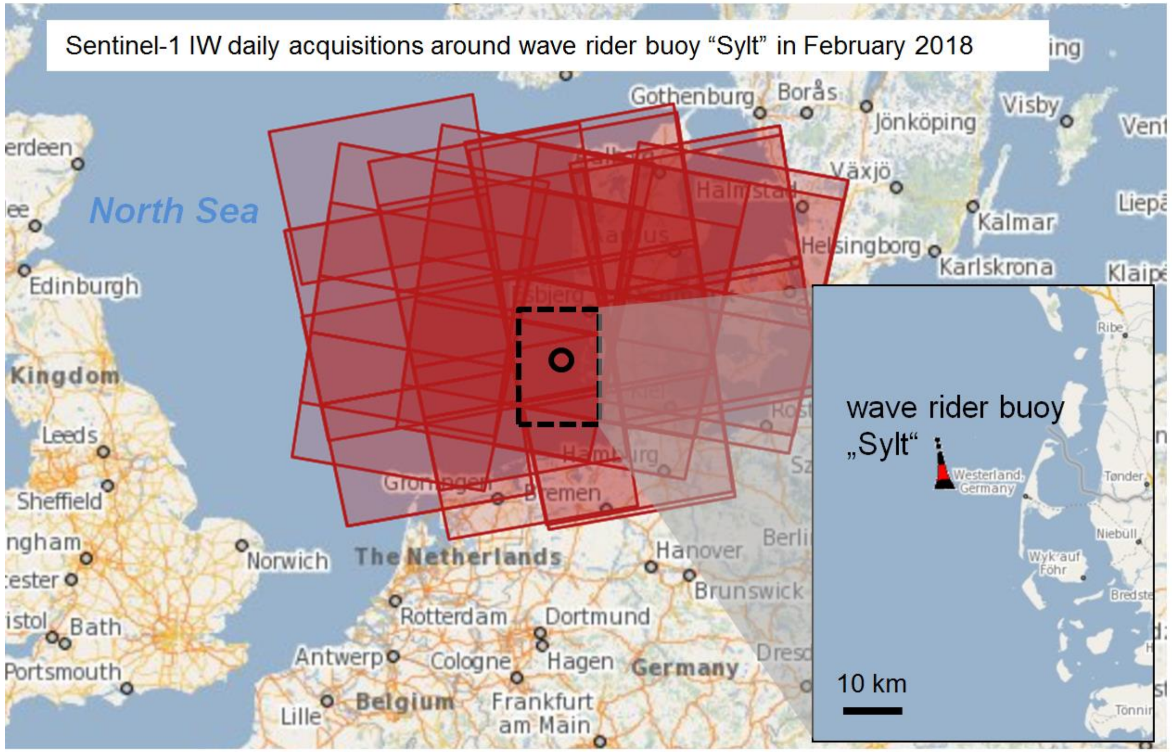
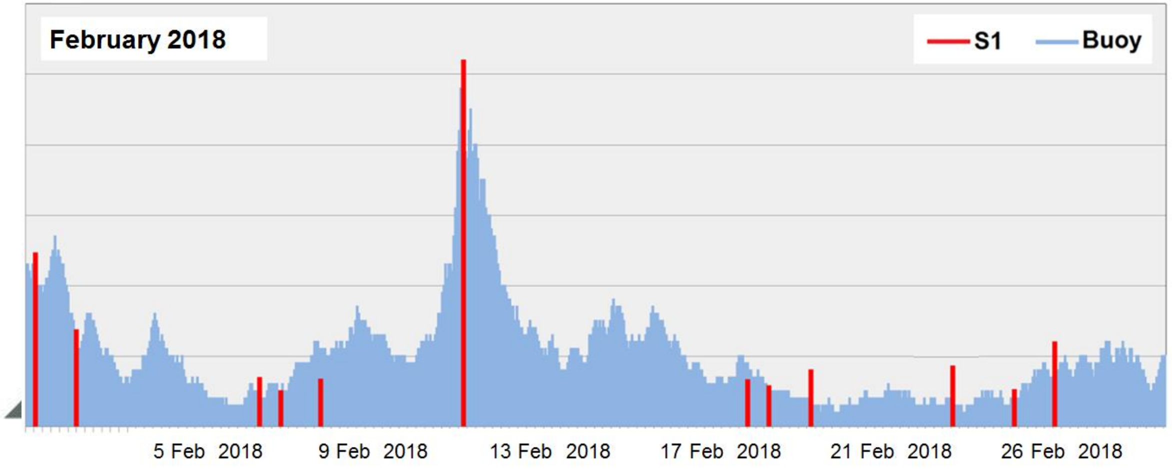
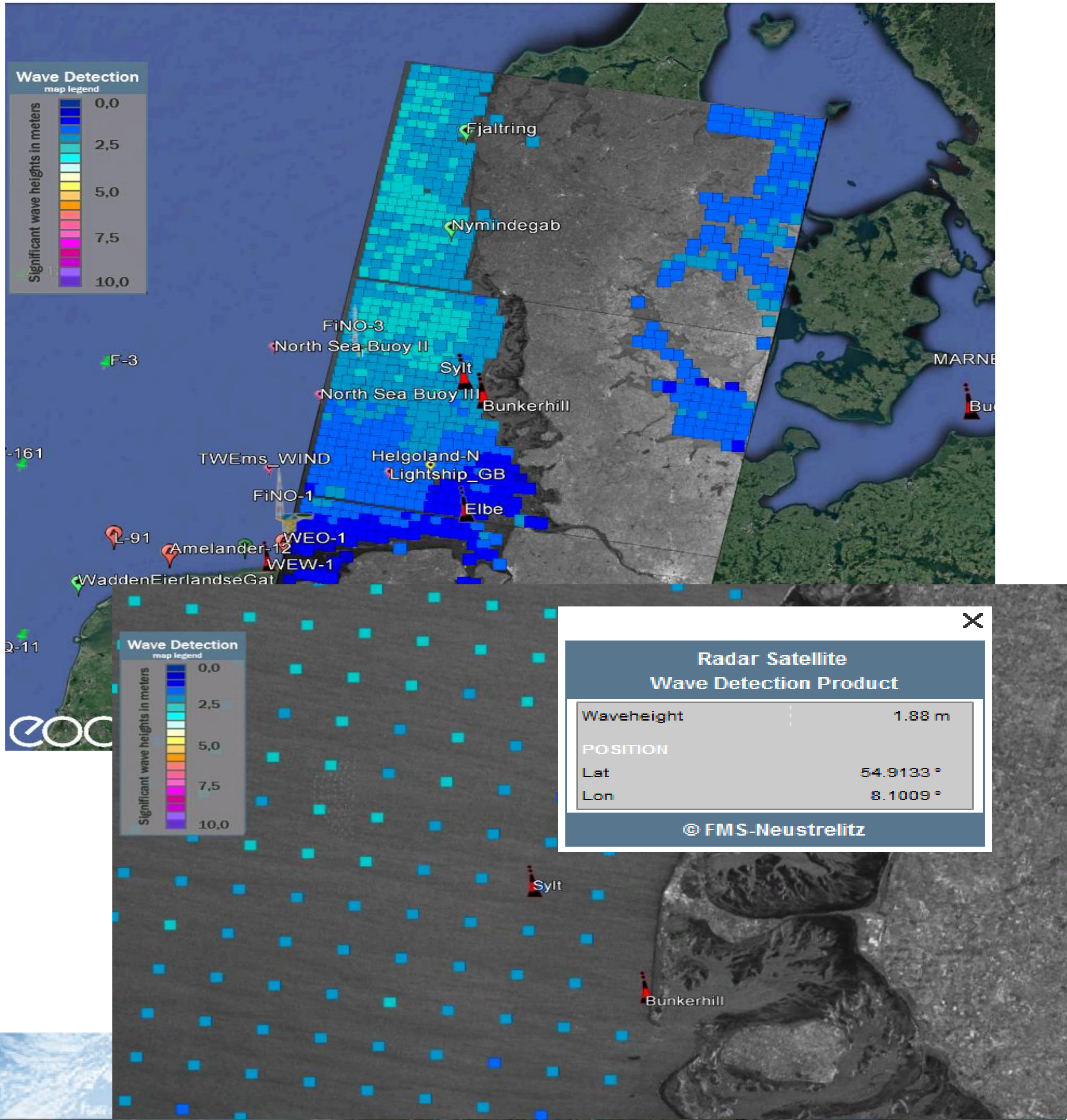
4.2. Acquisitions for a location S1 IW

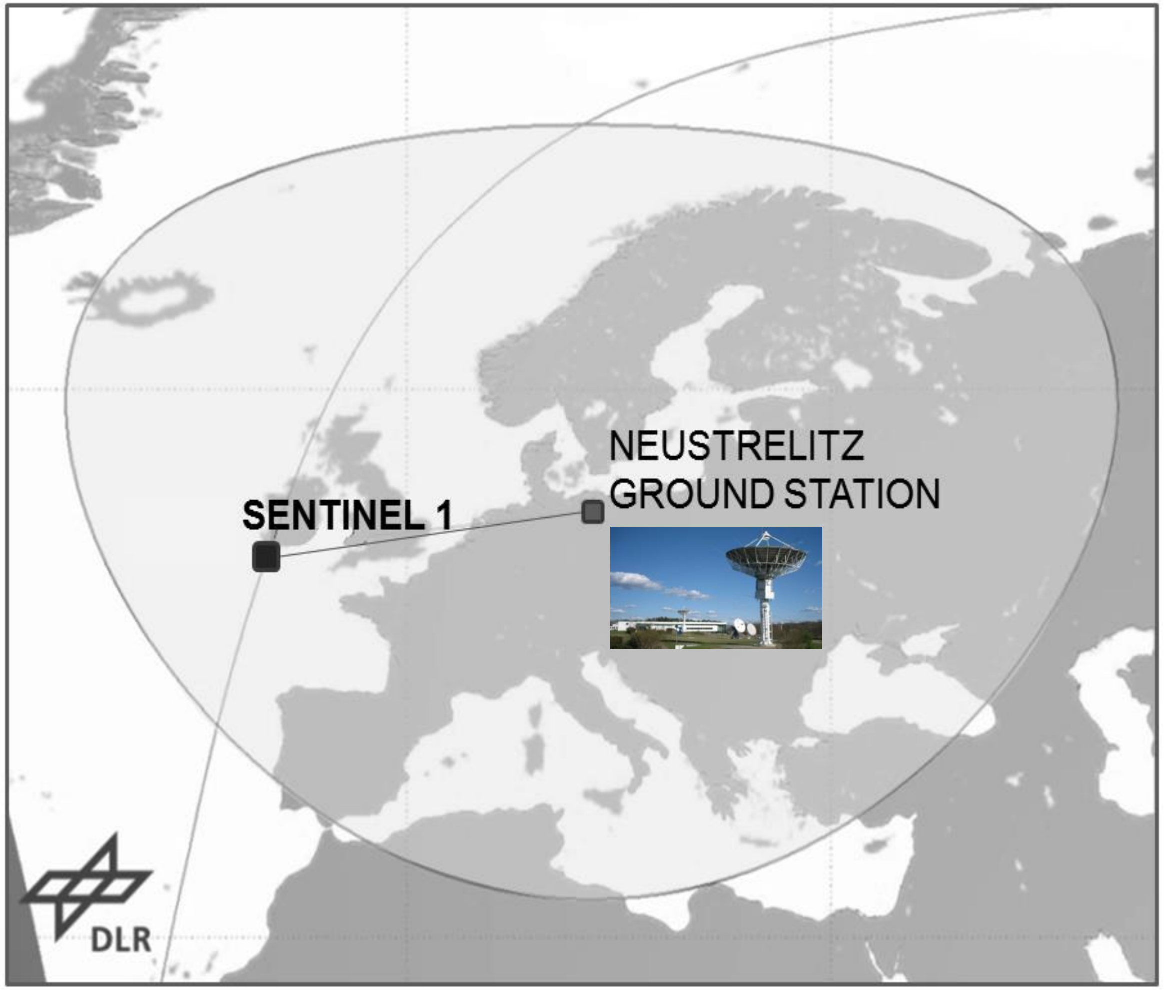




2018-03-28 05:41:27



4.3. Copernicus Local Ground Station Neustrelitz



Ground Station Neustrelitz, acquisition circle for Sentinel-1, 5 degree elevation. Inside of this area the data can be transferred from satellites to ground station directly after acquisition, without delay, for NRT processing.

Example S1 IW (2): Atlantic - Storm

Sequences of 12 S1-IW images , North Atlantic with Hs of ~ 9 m
coverage~ 250 km × 2200 km, Raster 3 km (60 × 80 = 4800 subscenes/image).